Ministry of Economic Development
Manatū Ōhanga
Intellectual Property Office of New Zealand

CERTIFICATE

This certificate is issued in support of an application for Patent registration in a country outside New Zealand pursuant to the Patents Act 1953 and the Regulations thereunder.

I hereby certify that annexed is a true copy of the Provisional Specification as filed on 30 July 1999 with an application for Letters Patent number 337015 made by CARTER HOLT HARVEY LIMITED.

Dated 10 September 2003.

Neville Harris

Neville Harris
Commissioner of Patents, Trade Marks and Designs

COMMISSIONER OF PATENTS, TRADEMARKS & DESIGNS
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337015

NEW ZEALAND

PATENTS ACT, 1953

PROVISIONAL SPECIFICATION

"Log Testing Apparatus"

We, CARTER HOLT HARVEY LIMITED, a company duly incorporated under the laws of New Zealand of 640 Great South Road, Manukau City, Auckland, New Zealand, do hereby declare this invention to be described in the following statement:

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The invention relates to apparatus useful in a method of deriving a (surrogate) measure of stiffness of sections of the stem of a felled tree (e.g., so as to be determinative of possible destinies of logs to be cut from the stem).

The timber industry faces a need to efficiently utilise its rather variable forest resource. Timber classification , for example machine stress grading, is currently done at the end of the production chain. This process results in wastage from processing which ultimately proves to have been inappropriate. Clearly, it would be more efficient to measure log properties early in the chain and process the logs accordingly.

In our New Zealand Patent Specification Nos.331527 (filed August 1998) and NZ333434 filed 17 December 1998 there are disclosed procedures in respect of the testing of felled tree stems or logs with a view to determining a destiny for that tree stem or log or logs to be cut from the tree stem.

New Zealand Patent Specification 331527 is directed to the selection of wood according to fibre characteristics so as to determine materials appropriate for the pulp and paper industry whilst New Zealand Patent Application 333434 is directed to timber or lumber cutting determinations but with the prospects of directing inappropriate tree stems or logs to the pulp and paper industry.

The present invention is directed to apparatus sufficiently portable and effective in usage which will allow the adoption of such aforementioned methods in the field.

It is therefore an object of the present invention to provide such apparatus and the use of such apparatus in the field for such tree stem or log assessment purposes. As used herein MOE is the dynamic modulus of elasticity derived by the product of (A) the square of the velocity of an appropriate wave propagation between the ends of a felled tree stem or a log (V^2) and (B) the specimen density ρ.

The present invention in one aspect consists in **apparatus for providing an indicator of or from which stiffness can be estimated for a felled log of known length L or measurable length L**, said apparatus comprising or including

sensing means capable of being placed in contact with a log end to detect the impulse and echoes thereof resulting from a striking of that same log end,

processing means to derive using an echo or echoes sensed by said sensing means a said indicator, and

display means to display said indicator or any derivative thereof received from said processing means,

wherein said processing means tests frequency transformed data derived from time based echo data with a view to deriving a measure or good estimate of fundamental frequency f_0,

and wherein L is or can be entered into said processing means,

sensing means capable of being placed in contact with or in close proximity to a log end to detect the impulse and echoes thereof resulting from a striking of the other or that same log end,

processing means to derive using an echo or echoes sensed by said sensing means a said indicator, and

display means to display said indicator or any derivative thereof received from said processing means,

wherein said processing means tests algorithmically frequency transformed data derived from *time based* echo data with a view to deriving a measure or good estimate of fundamental frequency f_0,

and wherein L is or can be entered into said processing means,

and wherein said processing means derives said indicator by reference to both f_0 and L.

Preferably said processing means tests all spectral peaks of the echo data for membership of a series from which a best value of fundamental frequency f_0 can be derived and related to the plane wave speed V and specimen length L by $V = 2L/f_0$ rather than by reliance on the identification of any single resonance peak.

Preferably in recognition that the characteristic frequencies may be shifted significantly from a harmonic series f_0, $2f_0$, $3f_0$, ... set, the processing means is programmed whereby a better indication of the fundamental frequency f_0, from which the speed V can be found, is obtained by identifying detected members of the resonant sequence and dividing the frequency of the highest member of the identified members by its harmonic number.

Preferably said processing means is programmed whereby it is programmed whereby said better indication of the fundamental frequency f_0 than an attempted direct measure of f_0 itself is obtained from at least the second harmonic.

Preferably said processing means recognises that whilst the natural resonance frequencies of stems and logs may be far from harmonic (principally on account of the asymmetry introduced by their taper or loading eg; when stacked) they may be transformed to a harmonic series by applying a correction which decreases as the harmonic number increases.

Preferably said processing means can transform detected members of a series of resonant frequencies f_n, as may be found in a log of sufficient length (e.g. such as in logs greater than 12 metres in length) that taper becomes appreciable, into multiples of a "true" fundamental frequency

f_0 from which a plane wave speed V can be derived by reliance upon $(f_n - n f_0)/f_n = ke^{-n}$ and such "true" fundamental frequency is then used in conjunction with log length L in the derivation of the plane wave speed V according to $V=2L/f_0$.

Preferably said processing means can transform detected members of a series of resonant frequencies f_n, as may be found in a log of sufficient length (e.g. such as in logs greater than 12 metres in length) that taper becomes appreciable, into multiples of a "true" fundamental frequency f_o from which a plane wave speed V can be derived by reliance upon $f_n/nf_0 - 1 = k/n^2$ and such "true" fundamental frequency is then used in conjunction with log length L in the derivation of the plane wave speed V according to $V=2L/f_0$.

Preferably said processing means discriminates against noise spikes in the spectra, peaks from unwanted modes inadvertently excited, or any other signals which differ from the spectral peaks sought and which have the desired relationship by using a comb filter comprising a number of frequencies ("centre" frequencies) which match the sought relationship, which can themselves be harmonic or have some other relationship, the comb filter having passbands wide enough to allow small deviations about each centre frequency,

forming the sum of the products of the actual spectral peaks and the comb filter, and

identifying as the sequence or filter which accounts for most spectral power, and, where necessary.

deciding between two filters which produce equal power sums on the basis of the comb which produces the least frequency offset between the actual spectral peaks and the filter centre frequencies.

Preferably said processing means uses such transforms to convert a harmonic series with a defined base frequency f_0 to a non-harmonic series, thereby defining the centre frequencies of a comb filter with which the actual series may be compared, without the need for all members of the actual series to be present.

Preferably said processing means can calculate a confidence number to be displayed by said display means to indicate the likelihood that the indicated velocity is correct or whether a re-measure is advisable based on the amount of power in the spectral peak series identified with a base value of f_0, compared with spectral power not accounted for, e.g that assumed to be in spurious noise spikes or non-longitudinal resonances inadvertently excited.

Figure 4 shows echo decay,

Figure 5 shows a preferred sensing head, and

Figure 6 is a block diagram of the preferred electronic hardware.

Measurements carried out by us on wood as it is dried from the green to dry state have shown that there is good agreement between the static bending modulus and the so-called dynamic MOE found from the formula

$$MOE = \rho V^2$$

where V is the velocity of longitudinal waves along the log or beam and ρ is the mass density of the wood, including its water content. This agreement is possibly because the effective measurement frequency is low (hundreds of Hz) rather than in the ultrasonic range often reported in the literature. Ultrasonic measurements show a water-dependent modulus. The low frequency agreement has profound significance for the log or timber industry; since the density of green wood is known to be about 1000 kg/m^3, regardless of the dry density. The modulus can therefore be estimated from a green velocity measurement alone. The dry value can be estimated as being perhaps 15% above this as the wood cellulose dries from saturation to equilibrium water content.

This document deals with three elements required in combination to make a fast yet portable field instrument by identification of impact-induced resonances found by Fourier analysis. Accurate measurement of the sonic velocity of logs or stems can be made in a time of a second from these resonances and a good estimate of the stiffness modulus found. The three elements are the measuring head, the signal acquisition and processing hardware, and the algorithms needed to interpret the resonance data.

In this respect see Figure 1.

General Instrument Requirements

The requirements for a portable, hand-held tool for log assessment, able to be used by a single operator in a yard or forest are

- Low weight and small size
- Ease of operation in obtaining the measurement
- Fast processing and display of answer, e.g. second.
- Low battery drain, e.g. operation for at least one shift on a battery
- Rugged construction with a degree of waterproofing.
- Robust processing algorithms able to handle variable quality data
- Low cost if many units are to be deployed by technically unskilled operators

Some of these requirements are potentially contradictory, such as ruggedized but lightweight construction, fast processing but small current drain. In particular, though small "laptop" style computers are available, it is unlikely that waterproofing, full shift operation and low cost can be easily achieved. It is generally more efficient to use dedicated hardware which incorporates the analogue signal acquisition, its digitization and processing into a characteristic spectrum, further software algorithms to interpret the data, and a small, low power display rather than the full screen of a computer. Such a configuration allows major savings of power, as will be described.

Sensing Head

Figure 5 shows the sensing head (1), comprising a piezo-style accelerometer **8** mounted on a body **9** which contains a cable entry **10** for the wires to the accelerometer **8**, and a switch **11**. The accelerometer is of a type which responds only to accelerations along the axis of the body. The wires are further protected mechanically by flexible tubing **12** which also prevents water ingress to the head **1** and which extends to the electronic unit (4, 5, 6) to be described.

The frequency response of the accelerometer may be chosen for the nature of the log expected. For normal forest work, a frequency response of 10 to 3000 Hz is adequate, but wider ranges may be advantageously used, particularly if the instrument is to be used in research applications.

It is preferable that the accelerometer incorporates a charge amplifier, since connection to the electronic unit may then be made through a cable of any length. The purpose of the switch **11** is to activate the signal acquisition circuits immediately prior to striking the log under test. It is desirable that the accelerometer is compliantly mounted on the body a, for example on a pad of silicone rubber **13**, as this enables the operator to press the head against the timber face of a log or stem end (e.g. of log 2) and maintain good contact independently of any hand movement. If the accelerometer mount is rigid, spurious acceleration signals may be generated if the flat face of the accelerometer is inadvertently rocked against the timber. A thin cap **14** of material such as neoprene rubber is fixed over the end of the head so as to be in contact with the accelerometer end face. The purpose of this is to provide some protection for the accelerometer against inevitable build up of debris such as resin from the logs under test. The cap may be cleaned or replaced. Tests have shown that 1mm of a hard rubber does not significantly impair collection of acoustic signals from logs.

To take a measurement, it is sufficient to press the assembly against the end face of the log **2**, depress the switch **11** (an action designed to encourage pressure contact with the timber) and strike the timber cleanly but not forcefully with a mallet or

hammer **3**. Pressure contact must be maintained for up to half a second while the sound waves within the log decay.

Signals may be collected reliably with this head **1** regardless of the nature of the cross-cut face; for example, the deep ridges produced by the hydraulic saws in automatic harvesters such as the WARRATAH™ generate signals no different from more even surfaces. It is not necessary to embed the detector in the wood to achieve coupling, a fact that considerably speeds up the sounding operation. Experience has shown that neither placement of the head or the blow is critical. This is understandable since the system analyses many tens of reflections of the acoustic pulse in modes which incorporate the entire log, so the precise nature of the initial shock becomes unimportant. This is in clear distinction from so-called stress wave testers, where a single transit time of an acoustic pulse is measured. Clearly, for stress wave testers, the initial development of the pulse from a hammer-generated, localised, near spherical disturbance, to a mode filling the log may be a significant fraction of the first transit. Nevertheless, good practice seems to be to place both the head and position the blow perhaps a quarter of the distance from the log centre to the bark. Peripheral blows tend to encourage non-longitudinal oscillations of the sample, which are not wanted.

Experience shows that unskilled operators have the unshakeable belief that if modest blows produce results, then Herculean strikes must be even more effective. This tendency can be controlled by issuing a hammer of appropriate weight for the task. For logs and stems, a weight of 400gm is adequate. For lighter samples, such as sawn and dried framing timber, lighter mallets can be used. Only on very short logs of exceptionally large diameter have heavy hammers been beneficial in exciting clean resonances.

Electronic Unit

The electronic unit is shown by reference to function in Figure 1 as including the processing means (a combination of means 4 to electronically measure and control and means 5 to process using algorithms) and display means 6.

The two dominating considerations of this electronic unit are the high rate of decay of the signal coming from the wood, and the need to reduce power consumption as much as possible so that effectively continuous operation on small batteries for at least one shift is possible. Consideration of currents drawn by processors capable of performing the functions required here show that some automatic form of power saving is necessary.

Measurements of the attenuation of acoustic signals in wet wood show that the signal can fall by 60dB in 0.1s, in an approximately logarithmic fashion. The process

of Fourier analysis in this application can be thought of as a simple way of averaging the echo times of many reflections, since the fundamental frequency f_0 found by Fourier analysis is the inverse of the inverse of the echo time T . **(Fig 4)** The reception of many echos leads to an accurate average. It is for this reason that resonance-type instruments produce more consistent answers than single transit stress-wave timers. However the echo time in a long stem is typically 10ms. To detect 20 echos necessitates detecting signal for 200ms, and clearly by this time the amplitude will be very low if the attenuation is 60dB/100ms.

To obtain useful signals for a duration of 0.1 to 0.4s, the gain of the analogue amplifier is made to increase at a constant logarithmic rate , for example 20 to 60dB, over the course of the event to partially offset the natural attenuation. Amplifier offset voltages must be carefully controlled with such a strategy to prevent dc contamination of the final spectrum. In conjunction with this, high resolution A/D converters, typically 14 bit, are used so that useful resolution can still be obtained where the signal has fallen into the microvolt range (but is still above the noise background). If the initial acoustic signal is converted to a 3V amplitude signal, the level 100ms after this might be 3mV, which would give some resolution on a 14 bit converter set to 3V scale, since the least significant bit is 0.19mvolt. However, signals beyond the 100ms time frame would quickly fail to be digitized.

The provision of time-dependent gain is vital to extend the period over which signals can be usefully digitized. 20 dB of gain over the 100 ms described above would raise the signal at that time to 30mv, enabling useful digitization to be considerably extended.

A block diagram of the electronic hardware is drawn in **Figure 5.** The accelerometer **15** is coupled to an analogue amplifier **16** which incorporates a gain control function. The state of the entire instrument is controlled by two programmable logic devices numbered **18** (the event controller) and **19** (the intelligent power controller). When powered up, only parts of these PLDs are operative, and since they are not switching, standing current is very low. When the enable switch **20** is closed the PLD **18** turns on the Analogue section **16** and the A/D converter **17** , and digitized samples from the accelerometer are fed to the signal register **4(b)** in the PLD. If the signal exceeds a threshold, the event detector **4(c)** assumes that the log or sample has been struck. The event starts the logarithmic increase in the analogue amplifier gain, and initiates the Intelligent power controller PLD **5**. which powers up the microprocessor **21**.

The microprocessor **21** records a number of digitized values over an ensuing time. Typically, 2048 readings will be taken over 400 ms, following which the

analogue amplifier and A/D converter are turned off. The data are then Fourier transformed following appropriate windowing and filtering. The particular data record described combination will yield a maximum frequency of 2.5kHz with a resolution of 2.5Hz, which suits forest applications, but could be changed to suit other needs.

The power spectrum is then analysed by the processor **21** using algorithms discussed in the next section to extract a fundamental resonance f_0, and an answer displayed in the liquid crystal unit **22.** This can consist of a single value for velocity, (assuming a prior log length has been entered into the unit), using the formula

$$V = 2 f_0 L$$

where L is the length, or the value can be converted to a speed class, and the code for that class displayed, for example "green" to indicate a colour marker to be used.

Having initiated the display, the microprocessor returns to hibernation mode to save current, and reactivates after a time of for example 30s to turn the display off under the control of the intelligent power controller **19**.

It is necessary to manually enter some information, for example new log lengths. Operation of the key pad **23** is detected by the power controller PLD **19**, which activates the processor **21** long enough to store the new data.

The unit is configured to deliver the minimum necessary information to operating crews, but clearly the full detail of spectral information, which may be required for R and D operations, is potentially available. The logic of the controller **19** is configured so that by keyboard entries, it is possible to send the spectral information via serial port **24** to an external computer for graphical display or data recording. Conversely, data received at the serial port activates the power controller and thence the processor, so that the serial port can be used to control the operation of the device from an external computer.

Spectrum Interpretation

It is well known that exciting a beam or log of wood into longitudinal oscillation produces a disturbance which can be Fourier analysed into a series which is harmonic, and in which the speed of sound in the wood is given by

$$V = 2Lf_0$$

V is the speed of longitudinal compressional motions along the member, and since the lateral boundaries are stress free, is given by the well known relation

$$V^2 = E/\rho$$

where E is Young's modulus, and ρ the material density.

In samples of regular cross section, particularly where these are slender, higher resonances are closely harmonically related to the fundamental. Extraction of the modulus using the two equations above is simple since the fundamental is easily identified. The number of harmonics detected depends on the frequency characteristics of the exciting impulse. Wet wood is soft. Typically a hammer is arrested in a time of the order of a millisecond and the spectra cannot be expected to contain harmonics greatly in excess of the inverse of this time, i.e. greatly above 1 kHz. However, modeling studies we have made show that slenderness of the beam is a factor also. Thin beams or logs encourage the excitation of high harmonics, while short fat beams or logs do not.

In practice, there is a variety of circumstances where this picture requires modification to extract reliable values of the modulus.

In field use, samples may not be slender - a four metre saw log with a diameter of 50cm is a considerably "fatter" than a sawn beam 100 by 50mm, and because of the excitation spectrum and the log shape, few harmonics will be detected in the log compared with the sawn wood. A decision on which frequency should be identified as the fundamental may be less clear for the log. We have found that this can be exacerbated by the presence of unwanted noise spikes in the spectrum, or unwanted resonances arising from less than optimum hammer blows. Situations of poor spectra have been found to be inevitable in some physical locations, for example when obtaining spectra from the logs of cross-cut stems, when the log faces are relatively inaccessible. In development work, it is possible to repeatedly take a spectrum until by chance it is "clean". In a production tool, a high success rate in analysis must be available, and a built-in indication of the confidence in the answer is desirable.

It is also recorded in the literature that spectra from logs in stacks may differ from harmonic. We have observed that the fundamental can be typically 5% higher than the value expected from the resonance identified as the second harmonic, and values of 10% have been seen. Calculating MOE based on the fundamental or the second harmonic in this case would have a discrepancy of 20%, which is unacceptable.

Tests done on logs measured first in a stack and then unstacked on bearers show that it is the fundamental which is shifted most. The second harmonic is affected by about 1% by stacking effects, and higher harmonics, where seen, are approximately unchanged. As a rough guide, the second harmonic is a more reliable estimate of stiffness than the fundamental. Always, any frequency shift of the fundamental is positive.

However, some short logs, measured in isolation on bearers, still show a small

but measurable departure from a harmonic series, usually with the higher harmonics at frequencies below what would be expected.

In the case of stems, the departure can be enormous. Since stems are "slender" many harmonics can be excited in the region below 1000Hz, and the lowest member of the series, if the fundamental, has been observed to be as much as 40% above the value implied by the higher harmonics. This would lead to a difference of two in the predicted value of stiffness.

All the foregoing situations must be allowed for in the analysis software.

Finite Element modeling of the eigenmodes of the logs and stems has been carried out to gain an understanding of the factors involved in departures from harmonic series.

The results show that for a cylindrical log, the lowest resonance frequencies are closely harmonic. This remains true when the anisotropic elasticity of wood is included. The frequency of the fundamental mode is only slightly affected by the value chosen for Poisson's Ratio, which is fortunate since this parameter is ill-defined in wood. Further, no evidence was found that radial structure in logs, approximated by an inner core of low stiffness surrounded by a stiffer outer cylinder produced other than some average spectrum of the two; i.e. such internal structure is not responsible for unharmonic effects.

At a frequency when the wavelength across the log approaches the wood diameter, the longitudinal frequencies become lower than expected i.e. a harmonic pull-down of the kind described earlier is seen. Due to the fact that the sound speed across the log is of the order of one tenth the longitudinal speed, this condition may be reached at what may be surprisingly low harmonic numbers in "fat" logs. Model results showed that ill-defined body resonances prevailed at higher frequencies. In other words, the spectra of short fat logs might be expected to show a small lowering of higher harmonics compared to the fundamental, but few harmonics will be seen. This roughly accords with our observational experience. The theory shows that for non-tapering logs, not stacked, the best indication of stiffness comes from the fundamental.

The situation for stems is different because of their taper. Taper is the only parameter found which causes the resonances following the fundamental to be sharply lowered in frequency. However, the modeling shows that it is the low harmonics which are raised above the value expected from the wood modulus, while the high harmonics still indicate stem stiffness. As with non-tapered logs, when the transverse wavelength of a resonance frequency approaches the stem diameter, the harmonic frequency tends to fall lower than expected. Because for stems, the frequency at which

noisy to limit the number of peaks to be considered.

Given the length of a log and a likely range of sound speed, the possible range of frequencies for a fundamental is calculated and spectral peaks sought within that range. The search is done within velocity windows whose ranges are less than 2:1. Within such a window, the range of possible fundamental frequencies cannot overlap the consequent second harmonic range, and so allows fundamental and second harmonic to be distinguished. If no successful identification is ultimately made within this window, subsequent searches are made within modified velocity windows. This is generally not required. Most green *p. radiata* logs have velocities between 2.5 and 4km/s which fulfills the velocity criterion.

For each potential candidate for a fundamental resonance, a filter comb is constructed. For example, if the peak to be tested had a frequency of 300 Hz, a comb consisting of 300, 600, 900, Hz is constructed, and the energy measured within that comb by adding the power at the comb frequencies. For short logs, a deviation of a few percent is allowed, i.e. energy is considered to be part of the comb if it falls within a predetermined band about the expected centre, to take account of the effects described earlier which are encountered in practice.

A useful variation of this procedure, which takes into account the stacking effect, is to base the comb search on the second harmonic, since this is relatively little affected by stacking, and to allow deviations from harmonic to fall mainly at the fundamental frequency. The velocity, and modulus, are then calculated from the second harmonic by assuming that this is the frequency $2f_0$.

This procedure is repeated for all peaks which are candidates for the fundamental within its allowed frequency range. The preferred identification is that spectral peak whose comb accounts for the greatest quantity of spectrum power. A numerical confidence measure which follows from this procedure is the ratio of the power accounted for in the peaks within the comb to the sum of power in other peaks plus the background noise level.

In the search to identify harmonic members, no power considered in peaks which fall at frequencies which would lead to impossibly low velocities. The reason for this is that such peaks can be generated by moving the accelerometer head during the course of recording data. Nevertheless, their inclusion in the confidence measure gives operator warning that such an event might have happened.

It will be occasionally found, particularly with short "fat" logs, that only one resonance is seen. In that case, provided it produces a plausible velocity, it must be assumed to be the fundamental.

this is predicted to occur is high, the effect is unlikely to be seen and indeed we have not observed it.

Tapered-log modeling shows that it is the taper per wavelength which is important. The imbalance or asymmetry occurring in the oscillating mass and spring forces about each node in the log is the underlying cause of frequency shift. Thus the fundamental mode, where the stem is half a wavelength long, can be strongly affected. The taper per wavelength in the N^{th} harmonic is only 1/N of that in the fundamental. The higher harmonics are much less affected by the taper and yield the correct stiffness. Modeling shows, and our experience confirms, that to a reasonable approximation, if the fundamental resonance frequency is raised by a factor ke^{-1} over its value expected on the basis of the stem length and stiffness, the N^{th} harmonic will be raised by a factor ke^{-N} over its harmonic value. Resonances therefore fairly quickly reach their harmonic values.

We believe that the cause of the rise in the fundamental resonance of stacked logs noted earlier also lies in asymmetry similar to the case of the tapered stem. Now, the effect is that a log may be pinned to its neighbour in only two or three places. For low harmonics, this can produce a major elastic asymmetry and consequent lifting of the fundamental. Most of the nodal sections of the higher harmonics will not see the pinning points and their frequencies will be little affected.

The various cases described are illustrated in **Fig 2**, where f_N is the frequency of the N^{th} member of the harmonic series sought, and f_0 is the "true" fundamental, or lowest member of the series, from which the velocity and stiffness can be found. The lowest member f_1 coincides with f_0 if the log is slender and non-tapered.

This background of observation and modeling results provides the basis of the algorithms used to analyse stem spectra. While a velocity can be judged by an operator from a screen display of spectra, an automatic system needs to allow for noise peaks, non harmonic effects, and perhaps most confusing to an automatic process, missing spectral peaks which confuse the identification of a series.

The algorithm must reject occasional noise peaks in the spectrum, which means that as many as possible of the resonant peaks should be identified, since random noise spikes will not occur in harmonic ratios. It must allow for the fact that frequencies may be non-harmonic to a small extent in short logs and greatly so in stems and it should not require all members of a series to be present.

The identification system first considers only spectral signals above a threshold, for example those within 20% of the power of the largest spectral peak. It may be advantageous to smooth data in the frequency domain before doing this if signals are

The procedure is modified for stems where taper is important resulting in a grossly non-harmonic series. A range of fundamental frequencies is sought as before, but the comb generated is considerably modified. Because the procedure is more complex and suits the presence of many harmonics, it is only applied to logs above a preset length, for example 12m.

If f_0 is as before the "true" fundamental from which the speed in the tapered log can be found and the modulus calculated, the exponential deviation from a harmonic series described earlier can be expressed as

$$(f_N - Nf_0)/f_N = ke^{-N}$$

Here f_N is the frequency of the N^{th} harmonic, and k is a constant between 0 and 1, which must be determined. Having identified one peak as a possible fundamental (i.e. N=1), for a given value of k, a value of f_0 is defined, and a comb of frequencies can then be generated at which the other harmonics should fall. The power falling within the comb is summed as before, and the procedure repeated with different values of k to find the optimum match for that presumed fundamental mode.

This procedure will sometimes yield two values of k which generate equal summed powers. A second measure is therefore taken at each value of k to express how closely the comb is fitted. This is the sum of the deviations of each peak from its comb centre frequency. The choice is made on the basis of the most power and the best comb fit.

The next candidate resonance for the fundamental is then tested, and classed as a better identification or not on the basis of both the resonance power accounted for, and the closeness of fit to the comb. With a fast processor, computation time is acceptably short.

In effect, a transformation is being done to best fit the given resonances to a harmonic set, and does not require all member of a series to be present. It could begin by generating a comb by assuming that a particular peak was the N^{th} harmonic and generating a comb from that. In fact, the algorithm does this, testing each peak in turn to be a particular harmonic of an assumed series, and finding the goodness-of-fit for each combination. This is useful since some stem signatures have an ill-defined fundamental frequency.

The complexity of the these procedures is frequently not needed because many resonance spectra have an obvious interpretation. Their need is in the general case, when a reliable answer is needed in a high percentage of cases from less than perfect data, and the data itself must be used to indicate to unskilled operators whether or not

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the answer is reliable.

Stem average velocities can be advantageously used to more intelligently break stems into logs. We have found that the velocity varies along stems in a broadly similar way and can be represented by the sum of a cubic expression and a constant term. In Figure 3, the constant term in the cubic has been adjusted by calculation so that the transit time derived by integrating the speeds from the cubic expression along a particular stem equals the time found from the averaged velocity V along the stem. The curve drawn is the resulting prediction of speed along that stem. Also shown in Figure 3 as the stepped line are speeds subsequently measured in the sequence of logs made from that stem. Clearly in this example, a combination of reference information and stem-average measurement has enabled a considerable improvement to be made in velocity or stiffness estimation along the stem prior to making cuts.

Stiffness measurement is a parameter which has had recent prominence, both in regard to log and timber stiffness and the implications it has for the basic constituent fibres of the wood. Measurement of stiffness using so-called stress wave timers, that is to say electronic instruments which detect the time of flight of a sonic impulse along or across a piece of wood have been in use for many years. While it is generally accepted that they measure a quantity indicative of mechanical stiffness, for forest use, they tend to be of marginal accuracy, and relatively insensitive (due their inherent broadband nature) and therefore difficult or impossible to apply to long logs. Their fatal flaw is that they require double ended operation, i.e. detectors need to be placed at each end of the log under test. Logistically, this is unacceptable in forest use.

In 1986, Sobue demonstrated the excitation of longitudinal resonances from a log or beam which had been struck by a hammer, their detection by a single sensor, and their identification by Fourier analysis. However this process was well understood as a general analysis method in material analysis prior to that time. This development however demonstrated that single-ended testing of logs to obtain an indication of stiffness modulus was possible. In general, subsequent developments have used commercial elements such as spectrum analysers, or standard computers, which mean that true field-portability has not been achieved and it has not been possible to survey production quantities of timber.

DATED THIS 30th DAY OF July 1999
A.J. PARK & SON
PER [signature]
AGENTS FOR THE APPLICANT

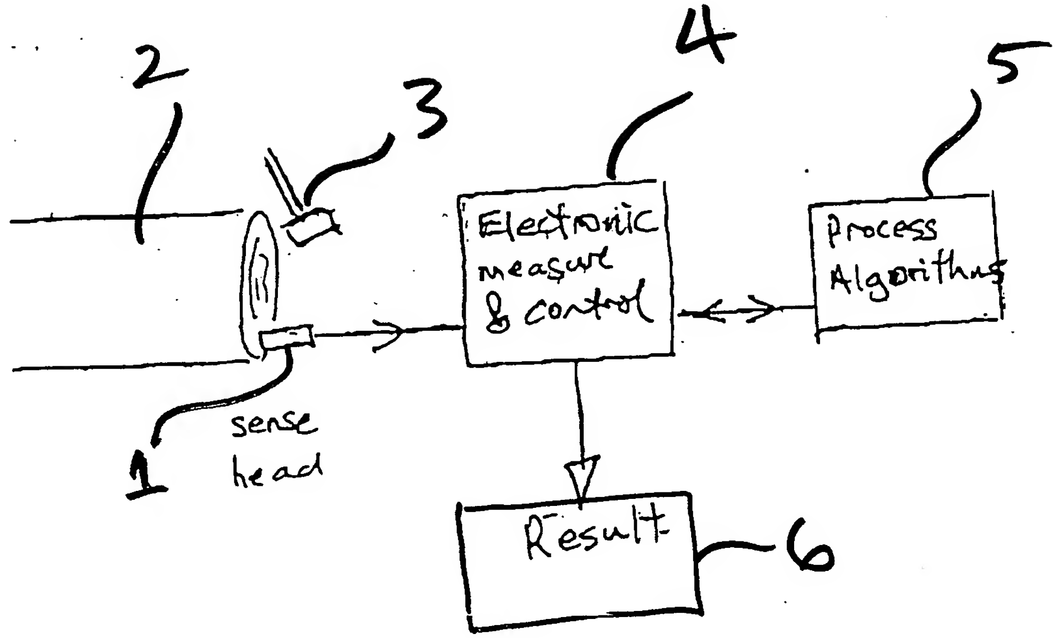

2
3
4
5
Electronic measure & control
Process Algorithms
sense head
1
Result
6

FIG 1

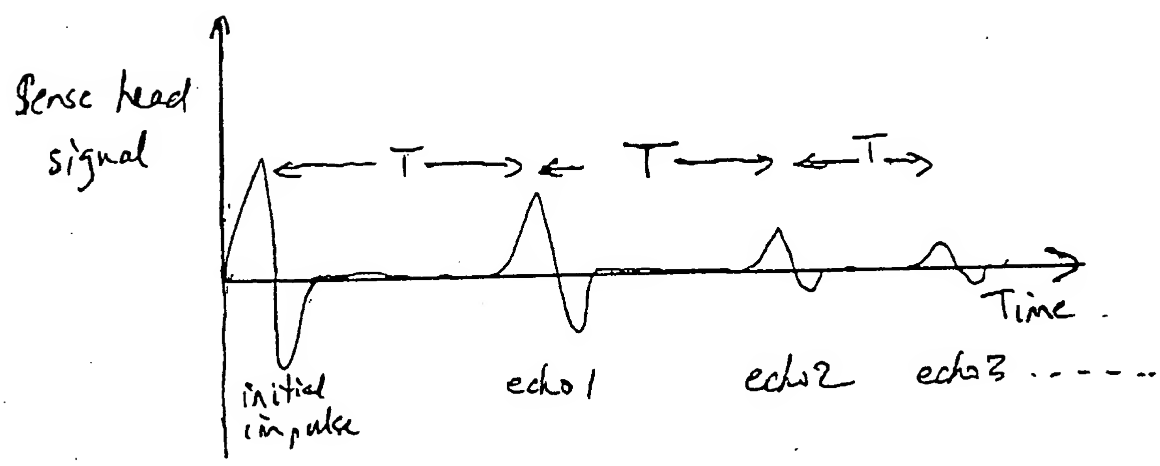

Sense head signal
T
T
T
Time
initial impulse
echo 1
echo 2
echo 3 . . . . .

FIG 4

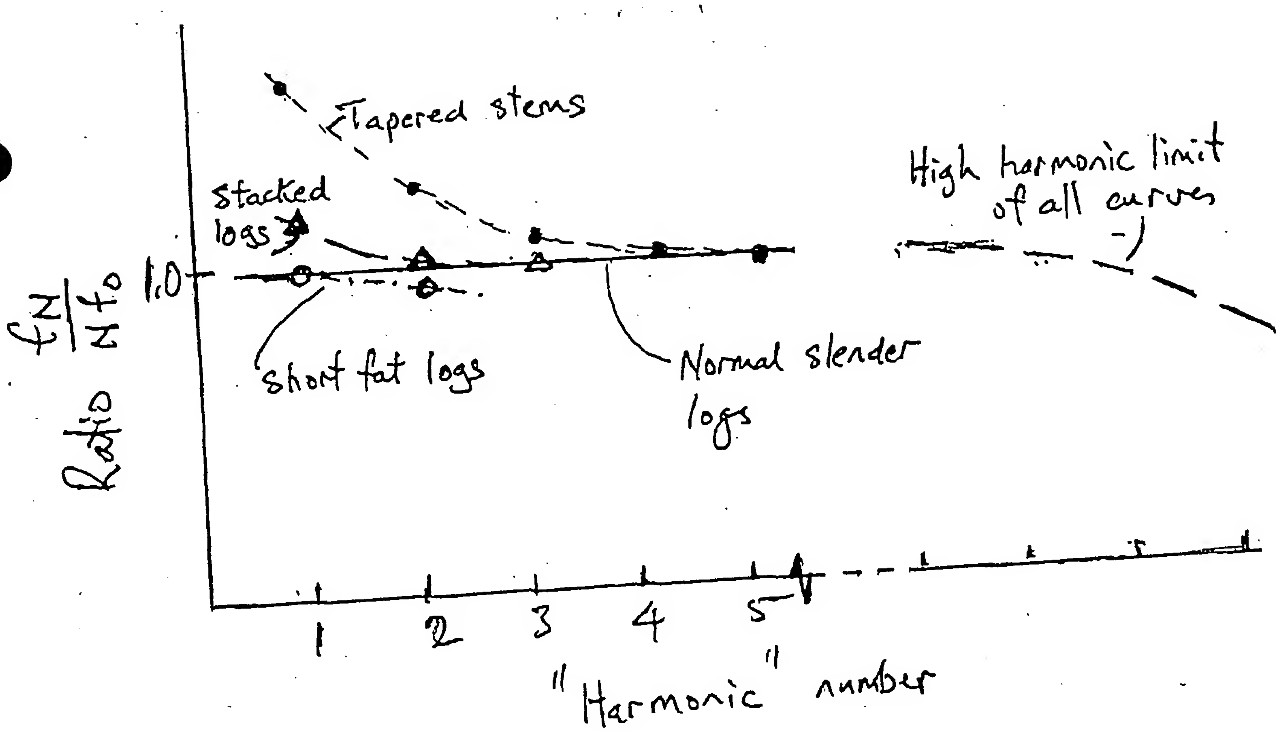
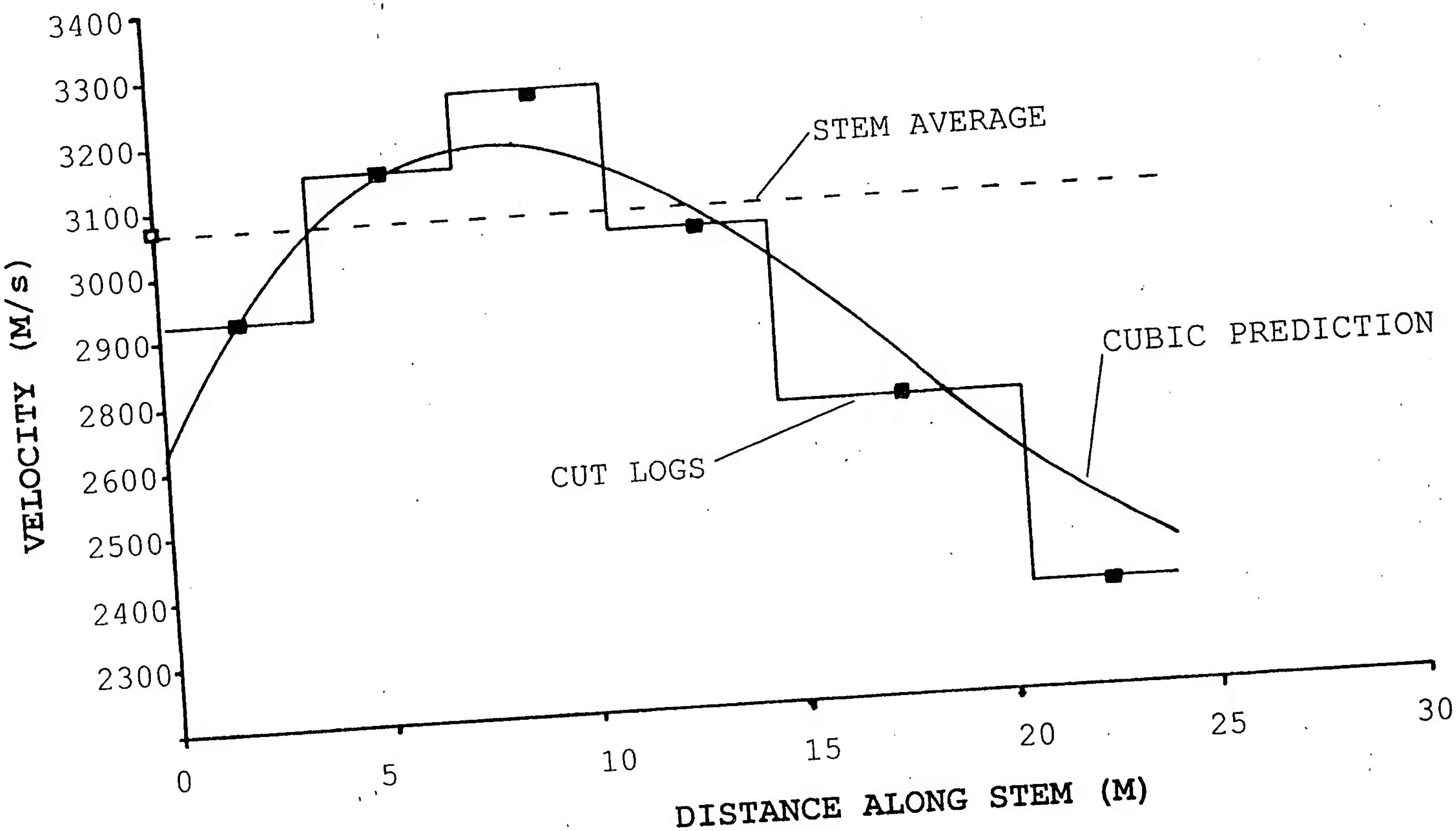

Tapered stems
High harmonic limit of all curves
Stacked logs
1.0
Ratio $\frac{f_N}{N f_0}$
Short fat logs
Normal slender logs
1
2
3
4
5
"Harmonic" number

FIG 2.



3400
3300
3200
3100
3000
2900
2800
2600
2500
2400
2300
VELOCITY (M/s)
STEM AVERAGE
CUBIC PREDICTION
CUT LOGS
0
5
10
15
20
25
30
DISTANCE ALONG STEM (M)

FIG. 3

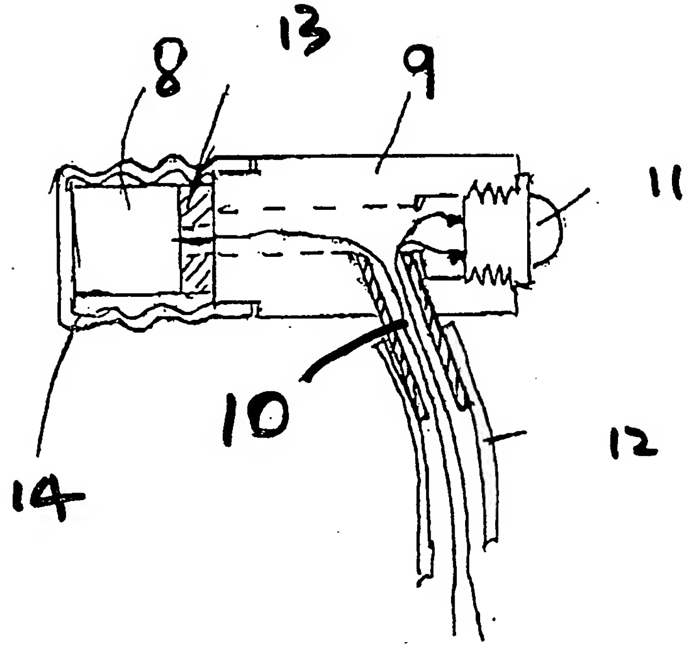


FIG 5

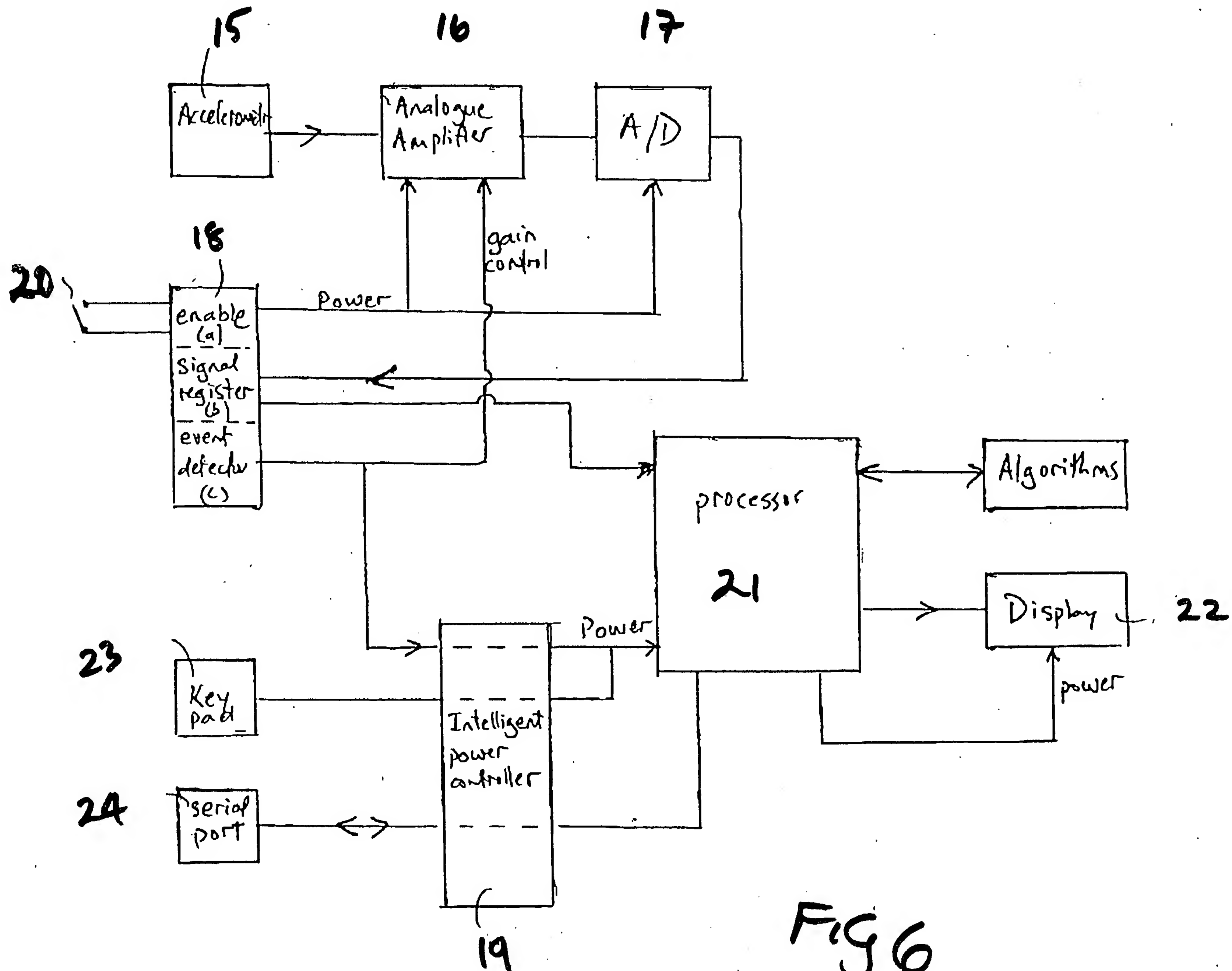

15
16
17
Accelerometer
Analogue Amplifier
A/D
18
20
enable (a)
signal register (b)
event detector (c)
Power
gain control
processor
21
Algorithms
Display
22
power
Power
23
Key pad
24
serial port
Intelligent power controller
19

FIG 6